Life Cycle Assessment of a Laptop Computer and its Contribution to Greenhouse Gas Emissions

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ABSTRACT

Mass production and extensive usage of personal computers such as desktops and laptops contribute to global warming. The demand for higher performance and faster processing capabilities make new models of laptop computers obsolete in a relatively short amount of time: the average lifespan of a laptop is typically between 3 to 4 years. In this paper, a life cycle assessment (LCA) is used to examine the full life cycle of a laptop computer from materials acquisition to manufacturing, use, and end-of-life disposition in terms of contribution to green house gas (GHG) emissions. From this analysis, the amount of GHG produced from the life cycle of a laptop computer is determined.

Introduction

Computers, printers, copiers, fax machines, VCRs, cell phones, and stereos are some of the electronic devices that are most commonly associated with e-waste. Among this group, computers are the biggest contributor to the amount of waste being generated (William, 2004). When old computers become obsolete or lack the required functional capabilities, they often end up in landfills or get shipped to third world countries, where the wastes can become a major environmental and health concern (Carro, 2008).

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A great amount of energy and resources is required to build a laptop computer. A United Nations University study found that it requires around 1.8 tons of total raw materials and other natural resources to manufacture an average desktop computer with a monitor. According to the study, the production process of a desktop computer and a 17-inch CRT monitor requires 240 kilograms of fossil fuels, 22 kilograms of chemicals, and 1,500 kilograms of water. This is equivalent to a mid-size vehicle (Williams, 2004). Many of the components that require a great amount of energy during the manufacturing process, such as semiconductors, are destroyed during the recycling process and are never recovered. Hence, the author highly recommends that each user tries to upgrade his/her computer to extend its useful life before sending it to the landfill or putting it up for recycling (Williams, 2004). To fully understand the impact of a personal computer on the environment, a detailed study of the life cycle stages of a computer is required. To accomplish this task, a computer needs to be broken into functional units and each unit must be analyzed separately in each of the life cycle stages.

Methodology

A study by the U.S Department of Energy estimated that the production and usage of computers accounted for 2% of the total global greenhouse gas (GHG) emission in the United States (Masanet et al., 2005). There are an estimated 3.95 million laptop computers in California. In this study, the amount of GHG generated from the time of a laptop's manufacture through its disposal is assessed using life cycle analysis.

<u>Analysis</u>

The main board of a laptop computer includes a printed circuit board assembly (PCB) and other small electrical parts such as resistors, condensers, and connectors.

Manufacturing these electrical parts within the main board is the predominant contributor to global warming during the pre-manufacture stage because it is during this time frame that much of the global green house gases are emitted. Substantial quantities of air pollution, wastewater, and solid waste are emitted during this phase (Choi et al., 2006). Based on the study by European Commission (2007), the energy used and CO_2 equivalent emission in the pre-manufacturing stage was found to be 1117.72 MJ, of which, 630.41 MJ was electricity energy. This is equivalent to a total emission of 71.15 kg of CO_2 eq. of GHG. Laptop manufacturing is a rather simple process; therefore, no major environmental impact is observed at this stage. Laptop manufacturing involves assembly and packaging. These activities require little electricity, and emit little air pollutants, wastewater, and solid waste. Material extraction, production, manufacturing, and distribution of a laptop computer are expected to consume about 1634 MJ of energy and emit approximately 90.51 kg of CO_2 eq. (European Commissions, 2007). To calculate the total GHG emission contribution from the production of a laptop, the number of laptops produced in the U.S. for this study was obtained from International Data Corporation (Bell et al., 2008). Table 1 summarizes the total annual number of laptops produced and annual amounts of energy consumed and GHG emitted.

Table 1: Total Laptop Production, Energy consumption, and GHG Emissions
(U.S., 2008-2012) (Bell et al., 2008)

Year	**Laptop Production Rate**	**Growth (%) Over Previous Year**	**Energy Consumption**	**GHG Emissions**
			MJ	**Tons of CO_2 eq.**
"2008"	33,837,000	22.2	5.53E+10	3.06E+06
"2009"	39,048,000	15.4	6.38E+10	3.53E+06

"2010"	44,369,000	13.6	7.25E+10	4.02E+06
"2011"	49,439,000	11.4	8.08E+10	4.47E+06
"2012"	52,771,000	6.7	8.62E+10	4.78E+06

The amount of electricity consumed in the product use stage depends on a variety of factors. The maximum energy output for a laptop computer ranges anywhere from 50 watts to 100 watts (Samwell, 2004). However, a typical laptop rarely reaches its maximum power capacity. The amount of energy consumed by a laptop depends on both the type of applications running and on its operational mode. In this project, the operational mode of the central unit and the monitor is treated as a single unit. The modes used to estimate the power consumption are ACTIVE (average), SLEEP (average) and OFF (average). The average power consumption for each operational mode and the annual power consumption are shown in Table 2.

TABLE 2: Laptop Adjusted Power Consumption and Annual Power Consumption (European Commission's Report, 2007)

	Electricity Used (kWh)	**Hours Per Year**	**Power Consumed Per Year** (kWh)
Active (Average)	0.032	2613	83.62
Sleep (Average)	0.003	2995	8.99
Off (Average)	0.0015	3153	4.73
TOTAL			97.34

The CO_2 conversion factors provided by the California Department of Energy are used to convert energy consumption (in kWh) into CO_2 emissions (in kg CO_2 equivalent) (Price et al., 2002). To get kg of CO_2 equivalent, the energy used was first multiplied by the Carbon factor (0.108 kg C/kWh). The result was then multiplied by 1 kg of CO_2/0.27 kg of C to get kg of CO_2 emission equivalent (1 kg of CO_2 = 0.27 kg of C). Based on this conversion, a laptop that consumes 97.34 kWh per year (Table 2) experiences annual GHG emissions of 38.94 kg of CO_2 eq.

Table 3 summarizes the projected growth for U.S. residential laptops from 2008 to 2012. The data on total PCs in Table 3 were derived based on the U.S. projected population growth from the U.S Census Bureau and estimated PC penetrations in the U.S. from the U.S Department of Energy (Horvath et al., 2007). Furthermore, an average of 2.59 persons per U.S. household and the U.S. residential PC penetration was 1 PC per household was assumed (Horvath et al., 2007).

TABLE 3: U.S population and laptop projections (U.S., 2008-2012)

Year	**Population Projections In millions**	**No. of Household In 1000s**	**Total Base PCs In 1000s**	**Total Base Laptops (25% of all PCs) In 1000s**	**New Laptops 18% In 1000s**	**New Laptops (Pop. Growth)**	**Obsolete Laptops In 1000s**	**Total Laptops In 1000s**
2008	303.598	117,219	117,219	29,304	5,275	259170	5,346	29,492
2009	306.272	118,251	118,251	29,562	5,321	258108	5,395	29,747
2010	308.936	119,280	119,280	29,820	5,368	257143	5,443	30,002
2011	311.601	120,309	120,309	30,077	5,414	257239	5,488	30,260
2012	314.281	121,344	121,344	30,336	5,460	258678	5,534	30,521

The end-of-life of a laptop computer occurs when it no longer meets consumer requirements or when it simply ceases to function properly. Laptop computers are usually not replaced because they are worn out or broken, but rather because of an increase in consumer demands for functionality, demands that are often triggered by the introduction of new versions of software. The end-of-life is extremely difficult to analyze due to the fact that not all recyclable parts of laptop computers are recycled. Often, the recyclable materials are dumped in landfills (Masanet et al., 2005).

To estimate the primary energy and GHG emissions associated with non-recycled laptops, the following assumptions are used (Masanet et al., 2005):

1. 92% of obsolete laptops ended up in landfills, 8% get recycled.
2. An average laptop mass of 2.52 kg.
3. An average diesel fuel consumption rate for solid waste collection of 9.1 liters/ton.
4. An average diesel fuel consumption rate for landfill equipment of 5.8 liters/ton.
5. An average energetic value of 40 MJ/liter for diesel fuel.
6. A conversion factor of 3 kg CO_2 eq/liter for diesel fuel combustion

This study calculated the total annual energy consumption and GHG emissions associated with all laptop computer activities. As expected, data analysis showed that the laptop production and use phases consumed the most energy and emitted the most greenhouse gas. Energy consumption and GHG emissions for the end-of-life phase were relatively low compared to other phases. Laptop production and usage accounted for more than 99% of energy consumptions and greenhouse gas emissions. The total annual energy consumption and GHG emissions are summarized in Table 4.

TABLE 4 Total Energy Consumption from Laptop Computers (U.S., 2008-2012)

Total Energy Consumption	**2008**	**2009**	**2010**	**2011**	**2012**
	(MJ)	(MJ)	(MJ)	(MJ)	(MJ)
Production & Manufacturing	5.5300E+10	6.3800E+10	7.2500E+10	8.0800E+10	8.6200E+10
Use Phase	1.0300E+10	1.0400E+10	1.0500E+10	1.0600E+10	1.0700E+10
End-of-life (landfill)	7.3900E+06	7.4600E+06	7.5200E+06	7.5800E+06	7.6500E+06
Recycled (Credit)	8.5500E+06	8.6300E+06	8.7400E+06	8.7800E+06	8.8500E+06
Total	6.5599E+10	7.4199E+10	8.2999E+10	9.1399E+10	9.6899E+10

Based on data analysis for the year 2008 above, laptop computer activities in the U.S. accounted for a total of 6.5599×10^7 gigajoules (GJ) of energy and 4.210×10^6 tons of CO_2 eq. emissions per year. Currently, California uses 9.54×10^8 GJ of electricity per year. The amount of energy consumed by laptop activities corresponded to 7% of total annual electricity used by California. This is a significant number considering that California is the most populated state in the U.S. The amount of annual GHG emissions mentioned above is equivalent to the annual GHG emissions of 700,000 midsize vehicles or to a single coal fired power plant ("Greenhouse Gas Equivalencies Calculator", 2008).

Conclusions and Recommendations

This study showed that laptop production and usage still pose a significant threat to the environment and to the sustainability of natural resources. Based on the study, some of the specific tasks that can be implemented to reduce energy consumption during the product use stage include the following:

- Turning off computer when not in use
- Setting up power management software to minimize energy use
- Buying laptop computers with Energy Star label
- Requiring the enabling of power management before shipping the product
- Educating consumers to understand and use power management in a proper way, and also offer guidance in purchasing choices

Another factor that can help reduce the amount of energy used during the product use phase is implementing the installation of multi core processors. A multi core processor can perform several tasks simultaneously instead of performing one task after the other. Hence, the operational time for the laptop will be lower, thus forcing it to consume less energy.

The production phase of a laptop is also energy intensive which indicates that the production of the motherboard and battery manufacturing are relevant areas to target for improvement. It is estimated that only a small percentage of laptops is sent to recycling centers, while the remainder ends up in landfills or is stored away. To encourage recycling practice, it is recommended that cities set up multiple recycling centers by enacting regulations. Another possibility is to make manufacturers responsible for end-of-life collections and recycling. The United States can implement a regulation similar to that implemented by the European Union so that obsolete computers and other electronic goods do not end up in landfills.

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